Standards for Engineering, Technology, and the Applications of Science

One of the most important messages of the Next Generation Science Standards for teachers, parents, and students is that science is profoundly important in addressing the problems we face at the beginning of the 21st century. The purpose of science education, broadly expressed as STEM literacy, is to equip our students with the knowledge and skills essential for addressing society's needs, such as growing demand for pollution-free energy, to prevent and cure disease, to feed Earth's growing population, maintain supplies of clean water, and solve the problem of global environmental change. Just as these grand challenges inspire today's scientists and engineers, the intent of the new standards is to motivate all students to fully engage in the very active practices of science and engineering.

The idea of integrating technology and engineering into science standards is not new. Chapters on the nature of technology and the human-built world were included in *Science for All Americans* (AAAS 1989) and *Benchmarks for Science Literacy* (AAAS 1993, 2008), and standards for "Science and Technology" were included for all grade spans in the *National Science Education Standards* (NRC 1996). Despite these early efforts, however, engineering and technology have not received the same level of attention in science curricula, assessments, or the education of new science teachers as have the traditional science disciplines. What is different in the *Next Generation Science Standards* (NGSS) is a commitment to fully integrating engineering and technology into the structure of science education by raising engineering design to the same level as scientific inquiry in classroom instruction when teaching science disciplines at all levels, and by according core ideas of engineering and technology the same status as core ideas in the other major science disciplines.

It is important to add at the outset, however, that including core concepts related to engineering and technology, and the relationships among science, technology and society, does not imply that schools are expected to develop separate courses in these subjects. At all educational levels it is essential that these concepts be closely integrated with study in the other disciplines of science. To that end, these standards include numerous examples of linkages with the other disciplines. Nor is the intention to discourage schools from offering courses at the middle and high school level that focus on engineering and technology. Such courses can include and go beyond these standards, and provide additional information on the wide variety of career opportunities afforded people who have a solid STEM background. The limited purpose of these standards is only to emphasize what all students are expected to know and be able to do as a result of the Pre-K–12 education, and this latest set of standards includes an increased emphasis on engineering and technology for the following reasons.

Rationale

The rationale for this increased emphasis on engineering and technology rests on two arguments in *A Framework for K–12 Science Education* (NRC 2011). One argument is inspirational; the other is practical. From an inspirational standpoint, the *Framework* emphasizes the importance of technology and engineering in solving meaningful problems. From a practical standpoint the *Framework* notes that engineering and technology provide opportunities for students to deepen their understanding of science by applying their developing scientific knowledge in different

contexts. Both arguments converge on the powerful idea that by integrating technology and engineering into the science curriculum, teachers can enable their students to use what they learn in their everyday lives.

One of the problems of prior standards documents has been the lack of clear and consistent definition of the terms science, engineering, and technology. A major contribution of the *Framework* has been to define these terms as follows:

> *In the K–12 context, "science" is generally taken to mean the traditional natural sciences: physics, chemistry, biology, and (more recently) earth, space, and environmental sciences. . . . We use the term "engineering" in a very broad sense to mean any engagement in a systematic practice of design to achieve solutions to particular human problems. Likewise, we broadly use the term "technology" to include all types of human-made systems and processes—not in the limited sense often used in schools that equates technology with modern computational and communications devices. Technologies result when engineers apply their understanding of the natural world and of human behavior to design ways to satisfy human needs and wants.* (NRC 2011, p. 1–3,4)

The *Framework*'s definitions address two common misconceptions. The first misconception is that engineering is just applied science. Although the practices of engineering have much in common with the practices of science, and engineers do apply their understanding of natural science in their work, engineering is a distinct field with its own goals, practices, and core concepts. The second misconception is that technology just refers to computers or other electronic devices; instead, it applies to all of the ways that people have modified the natural world to meet their basic needs and to realize their dreams.

Core Ideas

In the category of Engineering, Technology, and Applications of Science, the *Framework* identifies two core ideas and five sub-ideas, and specifies grade span endpoints for each sub-idea. The writing team used these endpoints as a basis for developing performance expectations. At the elementary levels the endpoints have been integrated into the grade-by-grade core ideas along with core ideas from the other disciplines, so that instruction in engineering and technology is seamlessly integrated into the science curriculum. At the middle and high school levels the endpoints were used to develop two grade band topical groupings of performance expectations at each level, corresponding to the two major core ideas: 1) Engineering Design, and 2) Links among Engineering, Technology, Science, and Society. Each of these four sets of topics consists of performance expectations, which combine the core ideas with practices and crosscutting concepts. In other words, standards in engineering and technology have been treated just like the standards in the traditional disciplines. Following is a brief summary of the core ideas.

ETS-ED: Engineering Design

The term "engineering design" has replaced the older term "technological design," consistent with the definition of engineering as a systematic practice for solving problems, and technology as the result of that practice. According to the *Framework*: " From a teaching and learning point

of view, it is the iterative cycle of design that offers the greatest potential for applying science knowledge in the classroom and engaging in engineering practices." (NRC 2011, p. 201-202) This idea contrasts with a common practice challenging children to build a tower out of newspaper with no guidance for how to go about solving the problem. Instead, students are expected to learn about three phases of solving problems:

Defining and delimiting engineering problems involves stating the problem to be solved as clearly as possible in terms of criteria for success and constraints, or limits.

Designing solutions to engineering problems begins with generating a number of different possible solutions, evaluating potential solutions to see which ones best meet the criteria and constraints of the problem, then testing and revising the best designs.

Optimizing the design solution involves a process of tradeoffs, in which the final design is improved by trading off less important features for those that are more important. This may require a number of iterations before arriving at the best possible design.

The *Framework* is also explicit about what students at different grade levels are expected to do in engineering design. This progression of capabilities is summarized in the *Framework* on page 70, as follows:

> *In some ways, children are natural engineers. They spontaneously build sand castles, dollhouses, and hamster enclosures, and they use a variety of tools and materials for their own playful purposes. Thus a common elementary school activity is to challenge children to use tools and materials provided in class to solve a specific challenge, such as constructing a bridge from paper and tape and testing it until failure occurs. Children's capabilities to design structures can then be enhanced by having them pay attention to points of failure and asking them to create and test redesigns of the bridge so that it is stronger. Furthermore, design activities should not be limited just to structural engineering but should also include projects that reflect other areas of engineering, such as the need to design a traffic pattern for the school parking lot or a layout for planting a school garden box.*
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> *Middle school students should have opportunities to plan and carry out full engineering design projects in which they define problems in terms of criteria and constraints, research the problem to deepen their relevant knowledge, generate and test possible solutions, and refine their solutions through redesign.*
> *High school students can undertake more complex engineering design projects related to major local, national or global issues. Increased emphasis should be placed on researching the nature of the given problems, on reviewing others' proposed solutions, on weighing the strengths and weaknesses of various alternatives, and on discerning possibly unanticipated effects.*

The increasingly sophisticated reasoning about engineering design that children are expected to develop across the grade levels can be expressed in terms of the following essential questions:

K–2: *What are different ways to solve problems and meet challenges?*

3–5: *How can people work together to create better designs?*

6–8: *How can different solutions to problems be compared, tested, and refined to arrive at the best design?*

9–12: *How are quantitative investigations, analyses, and simulations used to define problems, and develop and refine solutions?*

In using the core ideas to construct performance expectations at the middle and high school levels, the writing team has chosen to focus on the crosscutting concepts of: a) systems and system models; b) cause and effect, and; c) the influence of science, engineering and technology on society and the natural world. Systems and system models offer an especially fruitful way to approach the design process, since technologies can be thought of as systems that are embedded in larger systems, and that are frequently composed of smaller systems. Also, engineering design frequently involves creating, testing and improving physical or computer models and simulations, requiring understanding cause and effect in natural and designed systems. The societal dimensions are important because engineering is undertaken for a purpose—to solve a problem, meet a need or accomplish a goal. As students become more sophisticated, it is important for them to keep sight of the purposes of engineering, and to recognize that although technological decisions can have tremendously beneficial effects for people and the environment, they may also have unintended negative consequences.

ETS-ETSS: Engineering, Technology, Science and Society
The second core idea involves the connections among engineering, technology, science and society that are important for all people to understand in order to function and thrive in the modern world. This core idea includes the following sub-ideas.

The interdependence of science, engineering and technology includes the complementary ideas that scientists depend on engineers to produce technologies for them to use as tools for learning about the natural world; while engineers depend on scientists to provide inspirational new discoveries and accurate knowledge of how the world works. Engineering and technology drive each other forward in the research and development (R&D) cycle.

Influence of engineering, technology, and science, on society and the natural world also involves two complementary ideas. The first is that scientific discoveries and technological decisions affect human society and the natural environment. The second is that people make decisions that guide the work of scientists and engineers.

Unlike the three sub-ideas that describe three aspects of the engineering design process, these two sub-ideas are quite different, so it is difficult to capture them with a single set of essential questions. Following are quotes from the *Framework* that further elaborate these ideas, and essential questions, written by the writing team, to describe how students' understanding is expected to advance across the grades.

The interdependence of science, engineering and technology

The fields of science and engineering are mutually supportive, and scientists and engineers often work together in teams, especially in fields at the borders of science and engineering. Advances in science offer new capabilities, new materials, or new understanding of processes that can be applied through engineering to produce advances in technology. Advances in technology, in turn, provide scientists with new capabilities to probe the natural world at larger or smaller scales; to record, manage, and analyze data; and to model ever more complex systems with greater precision. In addition, engineers' efforts to develop or improve technologies often raise new questions for scientists' investigations. (NRC 2011, p. 210)

Essential questions:
K–2: *How can tools help us answer questions about the natural world?*

3–5: *How can we use technologies to make scientific discoveries, and use science to develop new technologies?*

6–8: *How do science and engineering build on and stimulate each other?*

9–12: *How do science and engineering interact in the research and development cycle?*

Influence of engineering, technology, and science on society and the natural world

From the earliest forms of agriculture to the latest technologies, all human activity has drawn on natural resources and has had both short- and long-term consequences, positive as well negative, for the health of both people and the natural environment. These consequences have grown stronger in recent human history. Society has changed dramatically, and human populations and longevity have increased, as advances in science and engineering have influenced the ways in which people interact with one another and with their surrounding natural environment. (NRC 2011, p. 212)
Not only do science and engineering affect society; society's decisions (whether made through market forces or political processes) influence the work of scientists and engineers. These decisions sometimes establish goals and priorities for improving or replacing technologies; at other times they set limits, such as in regulating the extraction of raw materials or in setting allowable levels of pollution from mining, farming, and industry. (NRC 2011, p. 213)

Essential questions:
K–2: *Where do the technologies that we use every day come from?*

3–5: *How and why are technologies created and improved, and how do they change our lives?*

6–8: *What are the factors that drive technological change, and how do the technologies that are created affect society and the natural world?*

9–12: *How can alternative technologies be evaluated based on their relative costs, risks, and benefits?*

In using the core ideas to construct performance expectations at the middle and high school levels, the writing team has chosen to focus on the crosscutting concepts of: a) cause and effect;

and b) stability and change. Cause and effect apply to the interdependence of science and engineering in the sense that changes in one area provoke changes in the other. Cause and effect also apply to the ways that technological decisions affect society and the natural world, and how societal needs and decisions set the agenda for scientists and engineers. In both cases students are expected to learn about the evidence that connects specific causes with specific effects. Stability and change likewise apply to both sub-concepts. Science and technology tend to be stable over time, but are subject to gradual and occasionally abrupt changes. The crosscutting concepts of stability and change contribute detail and texture to the interactions of science, engineering, technology, society, and the environment.

Connections to other disciplines

Crosscutting concepts in the *Next Generation Science Standards* are intended to communicate that there are no clear lines of demarcation between the science disciplines. There is a unity to science that transcends the fields of study. That seems especially true of the fourth discipline in the *Next Generation Science Standards*—Engineering, Technology and the Applications of Science. Engineering design, for example, is both a core idea and a practice of science and engineering, so it is embedded in the performance expectations of all of the disciplines, alongside scientific inquiry, at all grade levels.

One of the difficulties faced by the writing team was how to integrate the second core idea with the other disciplines. Certainly the reciprocal relationship between science and technology is best understood with regard to specific concepts and theories, as is the interrelationship among engineering, technology, science and society. But unlike engineering design, there seemed to be no direct route offered by the *Framework* to show how these ideas connect to the other disciplines of science. In order to integrate these ideas within the context of the other core disciplines we created two additional crosscutting ideas that capture in a general sense the core disciplinary ideas described in the *Framework* for the Interdependence of Science, Engineering, and Technology; and Influence of Science, Engineering and Technology on Society and the Natural World. As with the crosscutting concepts, we created progression matrices for these ideas and included them in the Crosscutting Concepts Foundation Box under those performance expectations that have a connection to these two core disciplinary ideas from Engineering, Technology, and Applications of Science (ETS).

Conclusion

Although the student performance expectations presented in this section are not new to science education, they nonetheless will require a new way of thinking in planning curriculum, instruction, and assessment. In the *Next Generation Science Standards,* engineering is not presented only as a means for teaching science; but rather as a field in its own right, including such core ideas such as trade-offs and optimization. Technology is not just the tools that students happen to use when doing science; but may constitute the purpose of a scientific investigation. And discussions of science, engineering, technology, society and the environment are not simply ways to enliven discussion, but become essential learning experiences with specific learning outcomes.